NASA Langley Research Center Contributions to the 3rd AePW High-Speed Working Group - HyMAX Computational Aeroelastic Predictions

January 21, 2023

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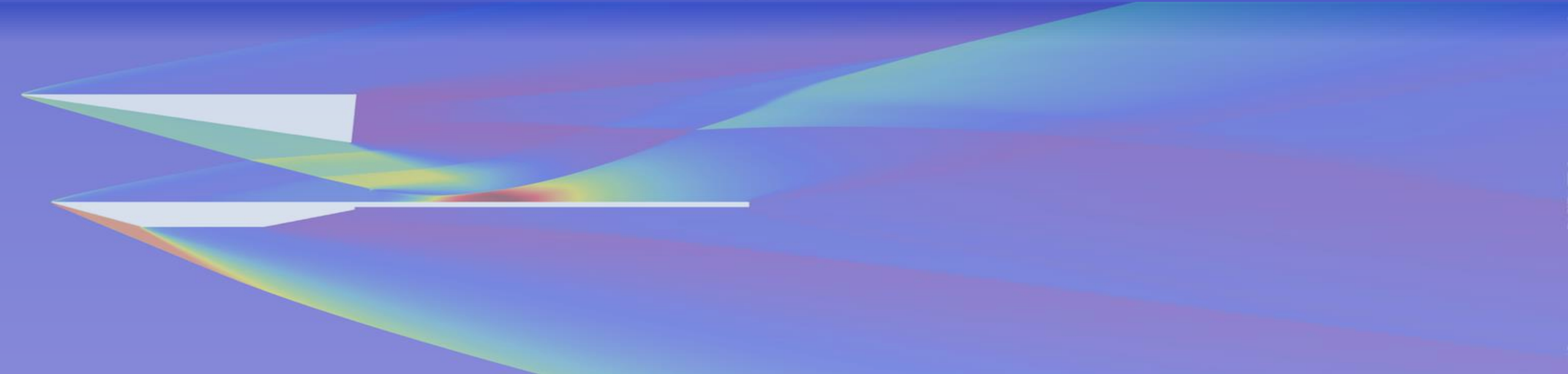
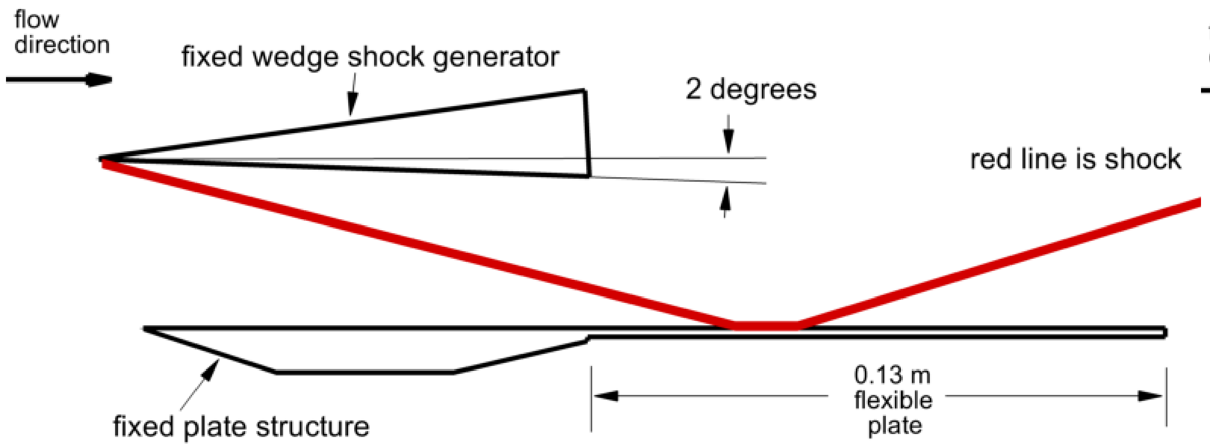
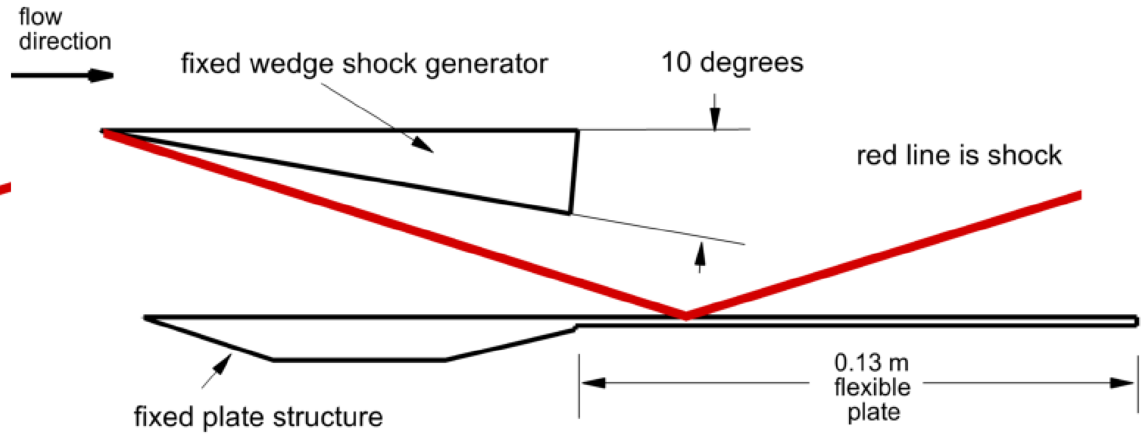


LaRC HyMAX Computational Aeroelastic Computations

- These simulations performed on configurations that will be used in an experiment in the Ludwieg tunnel at The University of New South Wales (UNSW) Canberra.
    - The experiment uses a fixed 3D wedge and flexible plate.
    - The start up transients create the aeroelastic response in the flexible plate.
    - The assumption in the present work is that the conditions at the center line of the wedge and plate can be considered quasi-2D.
    - Test section conditions: Mach = 5.8, Re = 7,100,000 /m, T_∞ = 75 K, T_{wall} = 300 K, P_∞ = 755 Pa, q_∞ = 17777 Pa.
- Analysis has been performed for two configurations: 2 degree and 10 degree turning angles.
    - Hymax_aepw3_2deg.stp and hymax_aepw3_10deg.stp CAD models used with Pointwise to generate grid.





LaRC HyMAX Computational Aeroelastic Computations

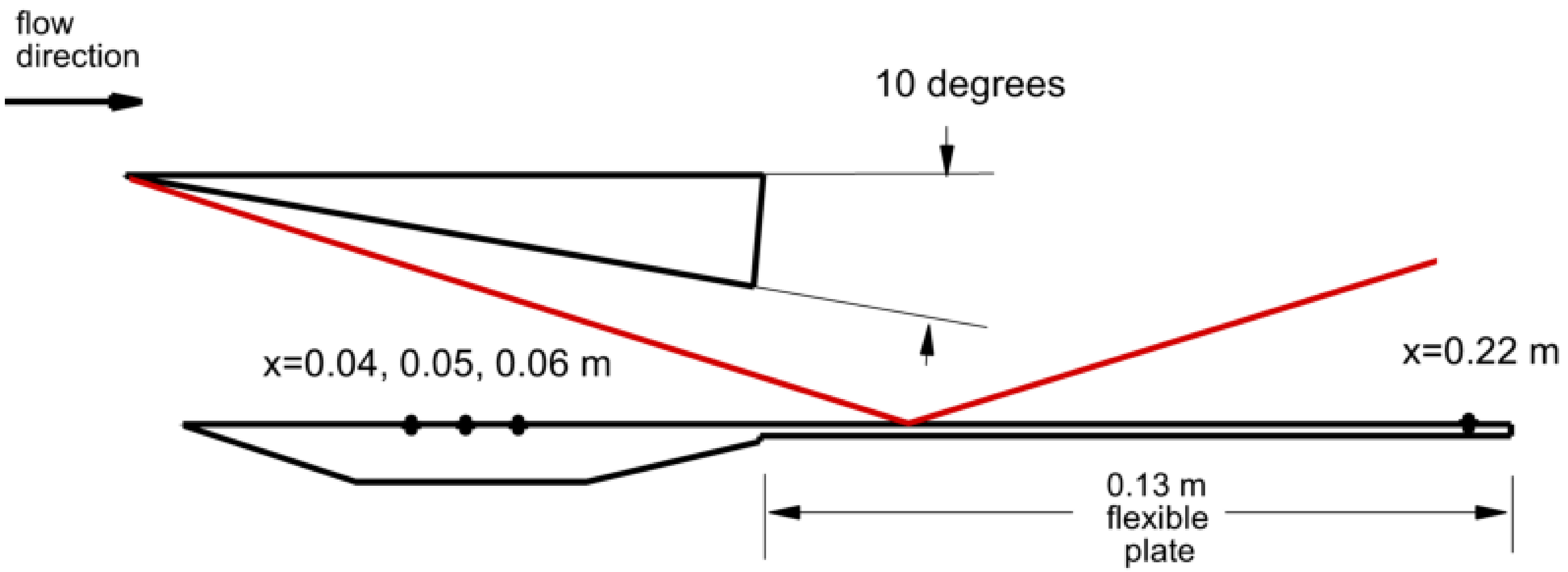
- The computational aeroelasticity code FUN3D v13.7 is used.
  - 2D models with reflection and extrapolation on the spanwise boundaries, Riemann boundaries upstream, top, bottom and downstream. (2D: 2 grid points in spanwise (y) direction)
  - FUN3D condition: Mach = 5.8, Re = 7,100,000 /m, T_∞ = 75 K , T_{wall} = 300 K, P_∞ = 755 Pa, q_∞ = 17777 Pa.
  - Calorically perfect gas
  - ALDFSS flux construction, adaptive entropy fix, Venkatakrishnan flux limiter (coefficient of 2).
  - 2nd-order optimal time stepping.
  - 10 degrees: $\Delta t = 5.76 \times 10^{-6}$ sec., laminar and turbulent solutions. Total of 35,800 time steps each.
  - 2 degrees: $\Delta t = 1.152 \times 10^{-5}$ sec., laminar only. Total of 28,700 time steps.
  - Turbulence model: SA-neg with QCR2020 Reynolds stress model, SARC.
  - Turbulence compressibility correction turned on.
  - This version of FUN3D allows the user specified flow initialization of conditions in arbitrary regions of the flow domain.

LaRC HyMAX Computational Aeroelastic Computations

- The final meshes used in the 10 degree and 2 degree were the result of successive refinements adapting to flow features.
  - Pointwise is not easily amenable to doing a grid refinement study, none was done.
  - All Mach, pressure and density gradients were refined.
  - Shocks, boundary layers and slip line behind the shock were well resolved, however, the expansion behind the wedge may have been underresolved.
  - 2 and 10 degree laminar and turbulent: $\Delta z_{wall} \sim 3\ \mu m$.
  - Final grids: 21.6 million grid points for the 10 degrees case, 18.4 million grid points for the 2 degrees case.

LaRC HyMAX Computational Aeroelastic Computations

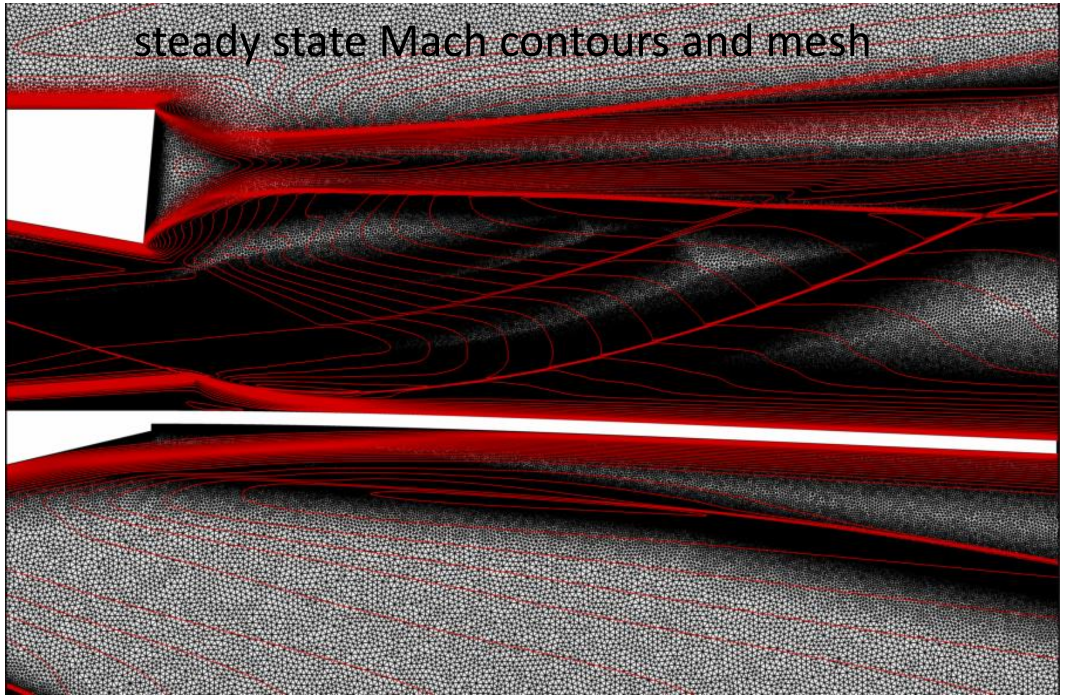
- Unsteady pressure and displacement data are taken at 4 points shown below.



LaRC HyMAX Computational Aeroelastic Computations

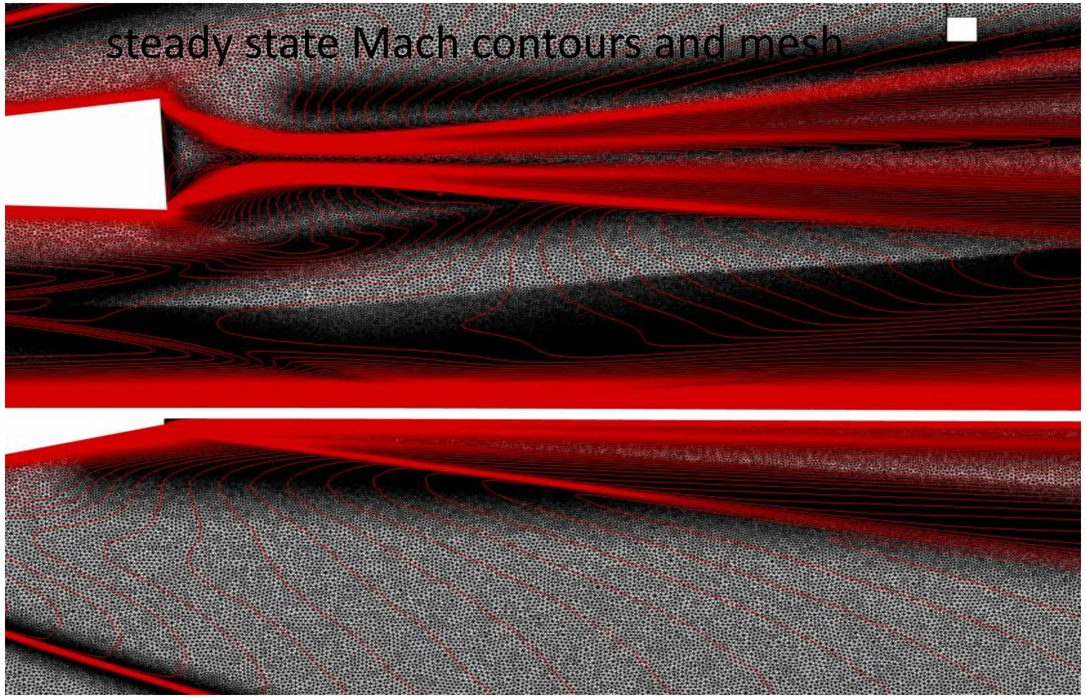
10 degree turning angle

- 21 million grid points
- Mixed element grid, blocks in boundary layer and prisms elsewhere.
- $\Delta z_{wall} \sim 3\ \mu m$



2 degree turning angle

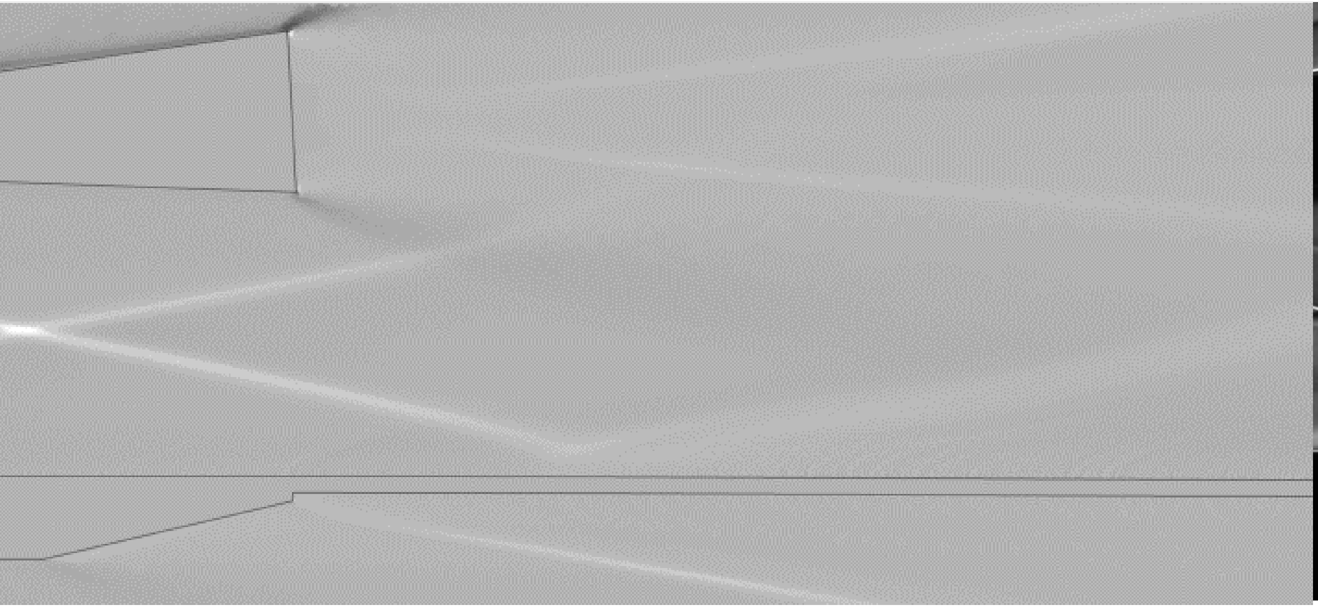
- 18 million grid points
- Mixed element grid, blocks in boundary layer and prisms elsewhere.
- $\Delta z_{wall} \sim 3\ \mu m$



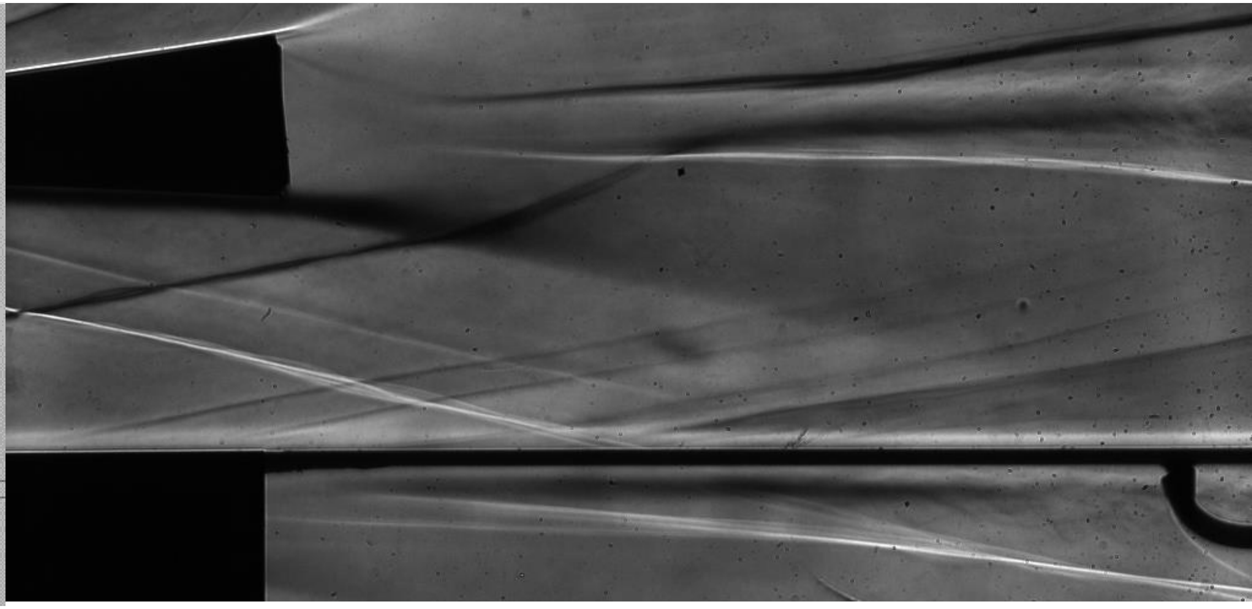
LaRC HyMAX Computational Aeroelastic Computations

2 degree turning angle

Computational Schlieren

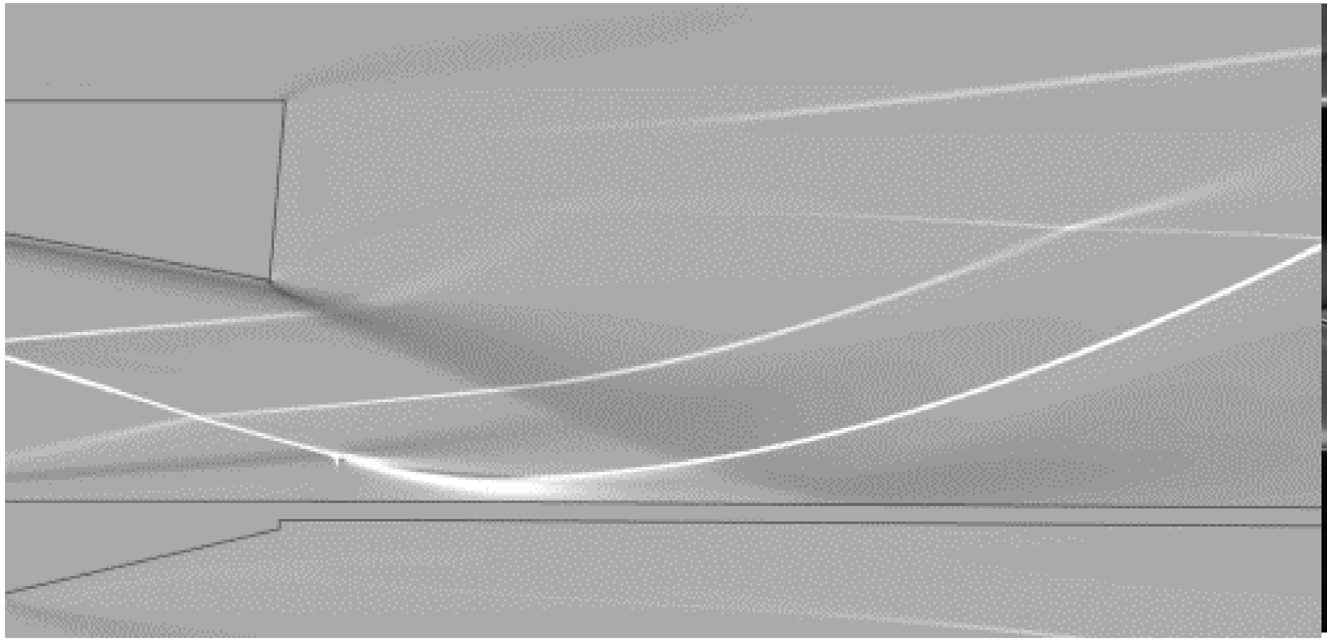


Experimental Schlieren

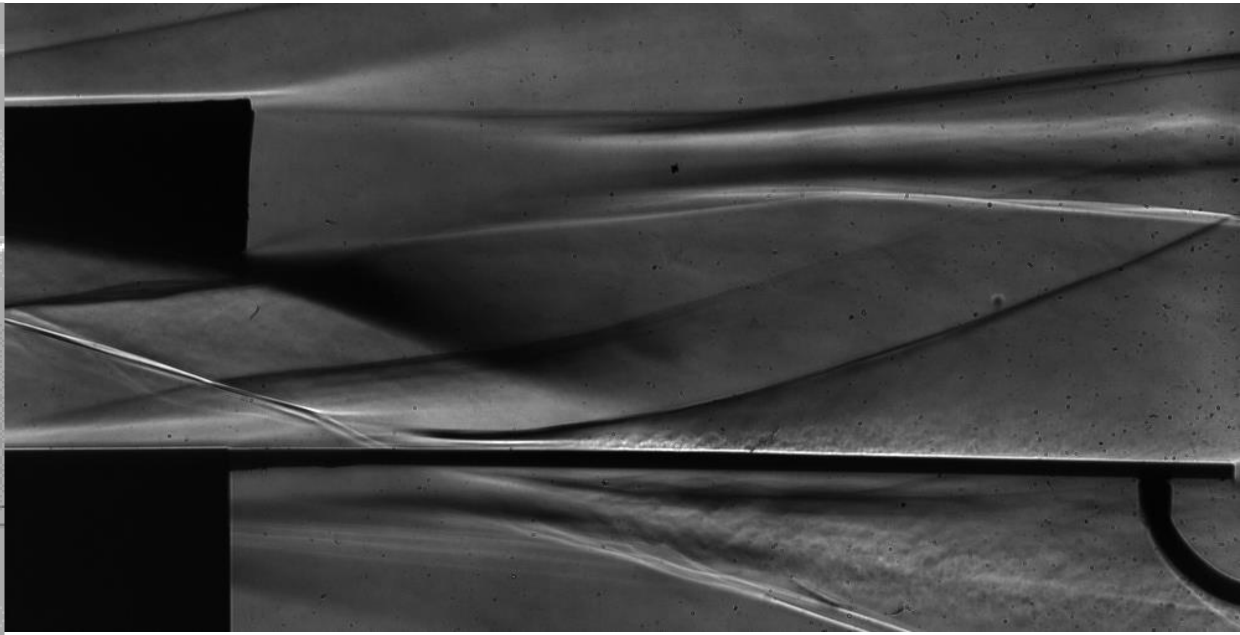


10 degree turning angle

Computational Schlieren

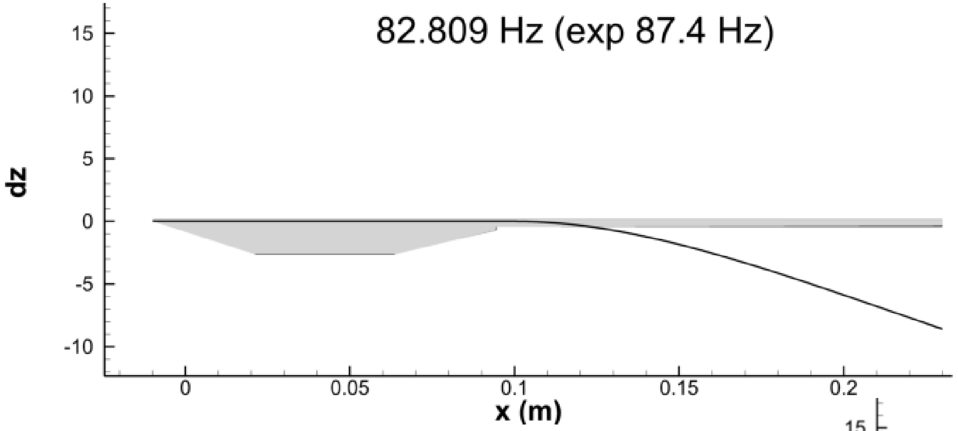


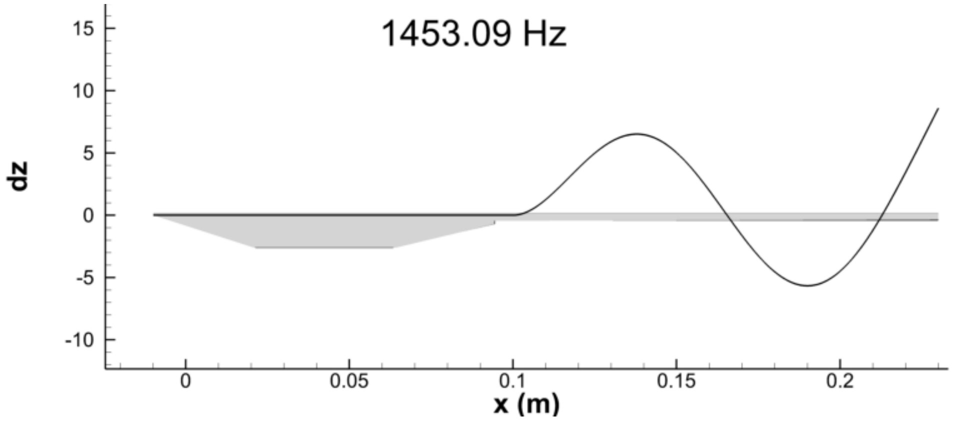
Experimental Schlieren

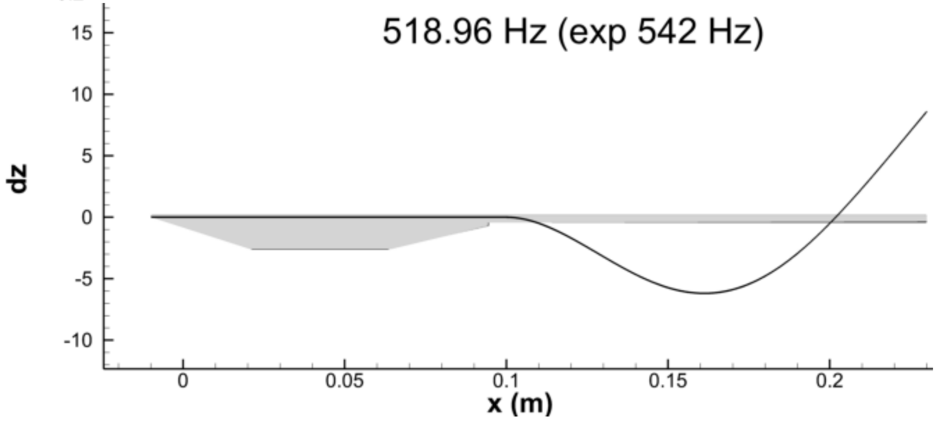


LaRC HyMAX Computational Aeroelastic Computations

- The linear modal structure solver in FUN3D is used.
  - Structure is modeled as a beam.
  - 3 structural modes are used, as shown below.
    - 2 correspond to longitudinal modes published in 2019*.
  - Zero structural damping.



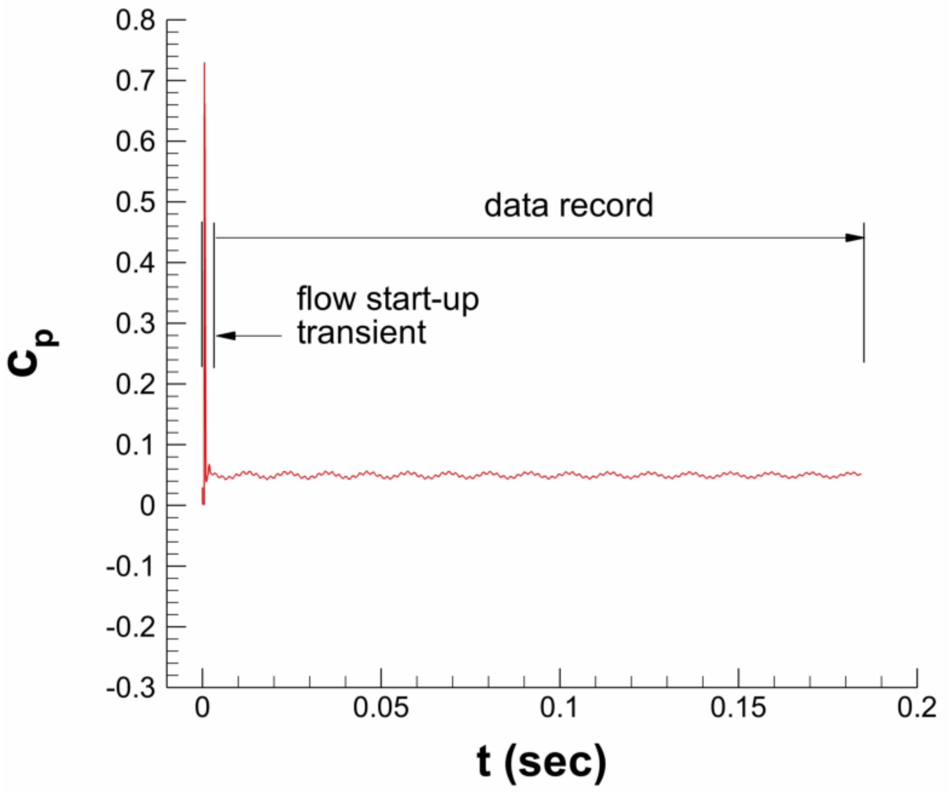




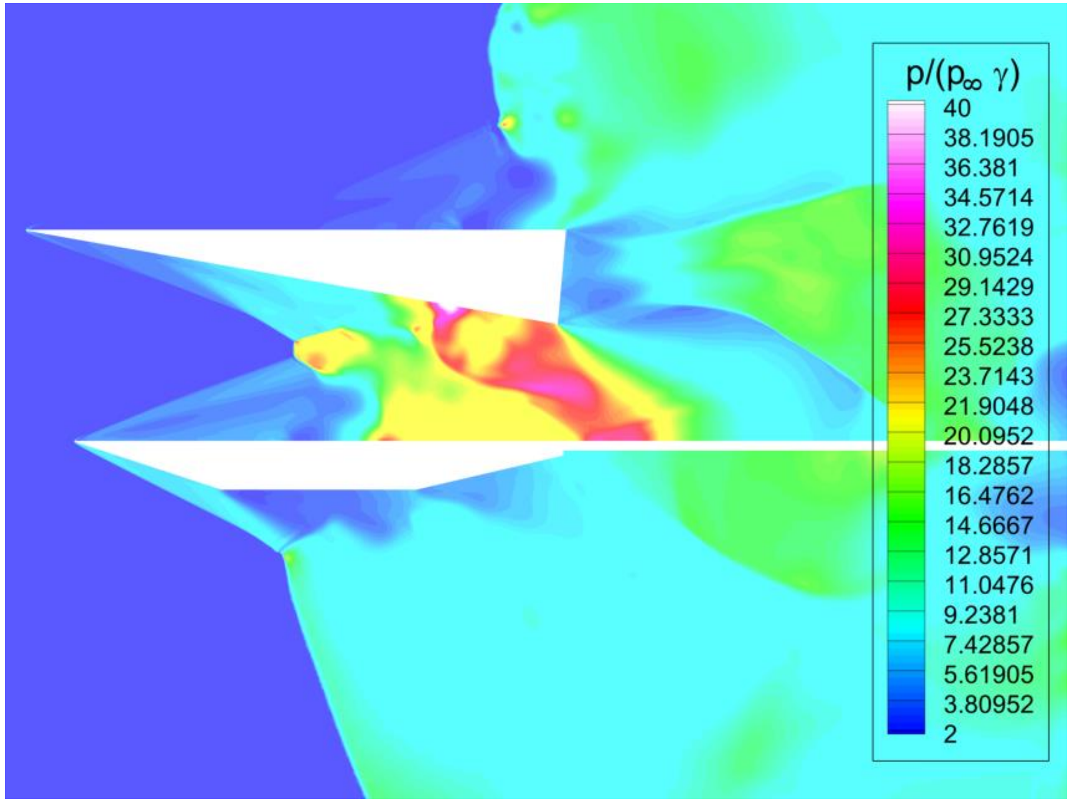
* Currao, Neely, Kennell, Gai, "Hypersonic Fluid-Structure Interaction on a Cantilevered Plate with Shock Impingement," AIAA Journal, Vol 57, No. 11, November 2019.

LaRC HyMAX Computational Aeroelastic Computations

- Flow initialized with zero velocity in test section.
  - This is an attempt to replicate Ludwieg tunnel start up
  - Upstream: Mach = 5.8, P_∞ = 755 Pa, T_∞ = 75 K
  - Initial transients die out after about 9 ms.
  - Wall boundaries: T_w = 300 K, no-slip.

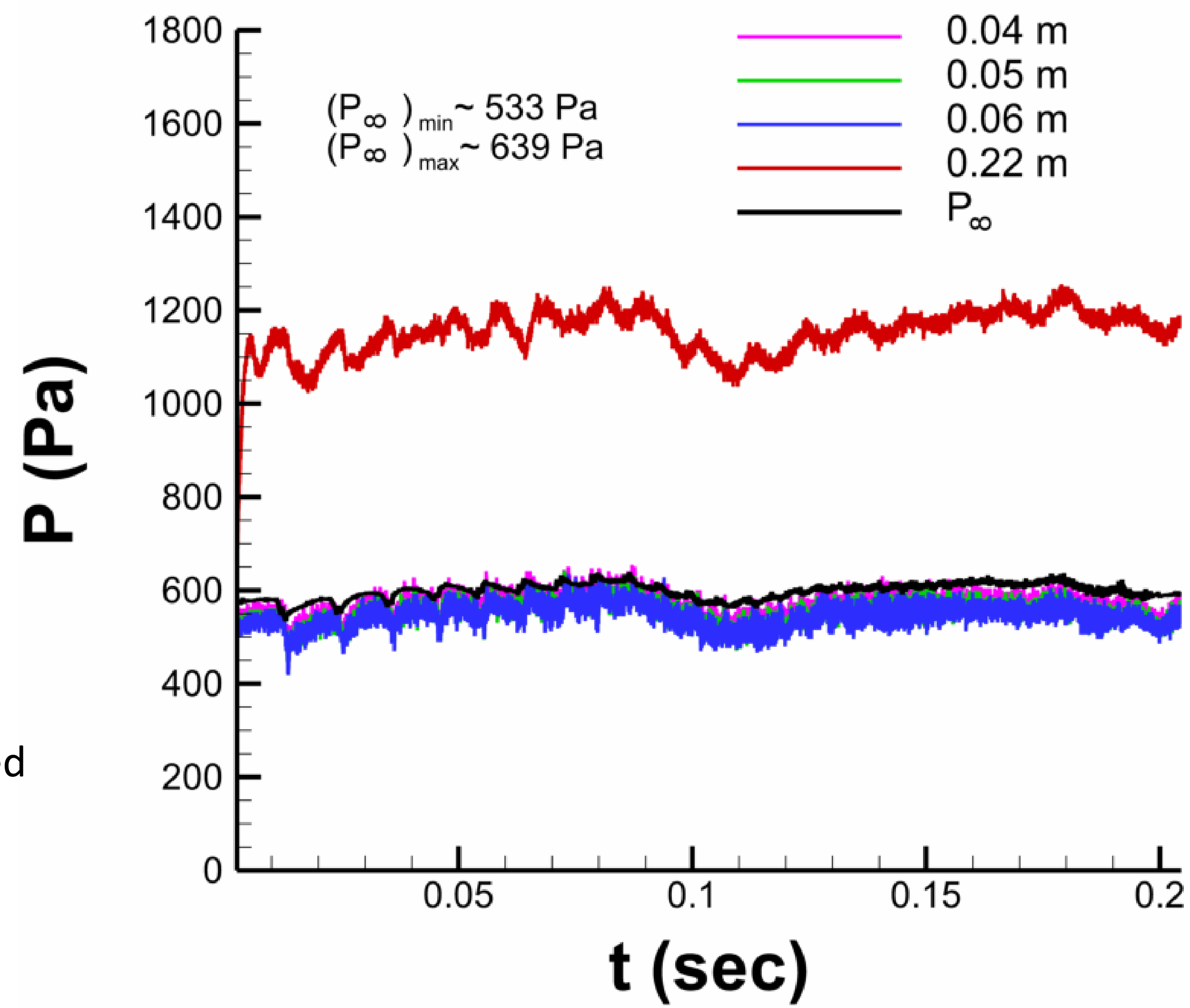


Flow at 0.23 ms

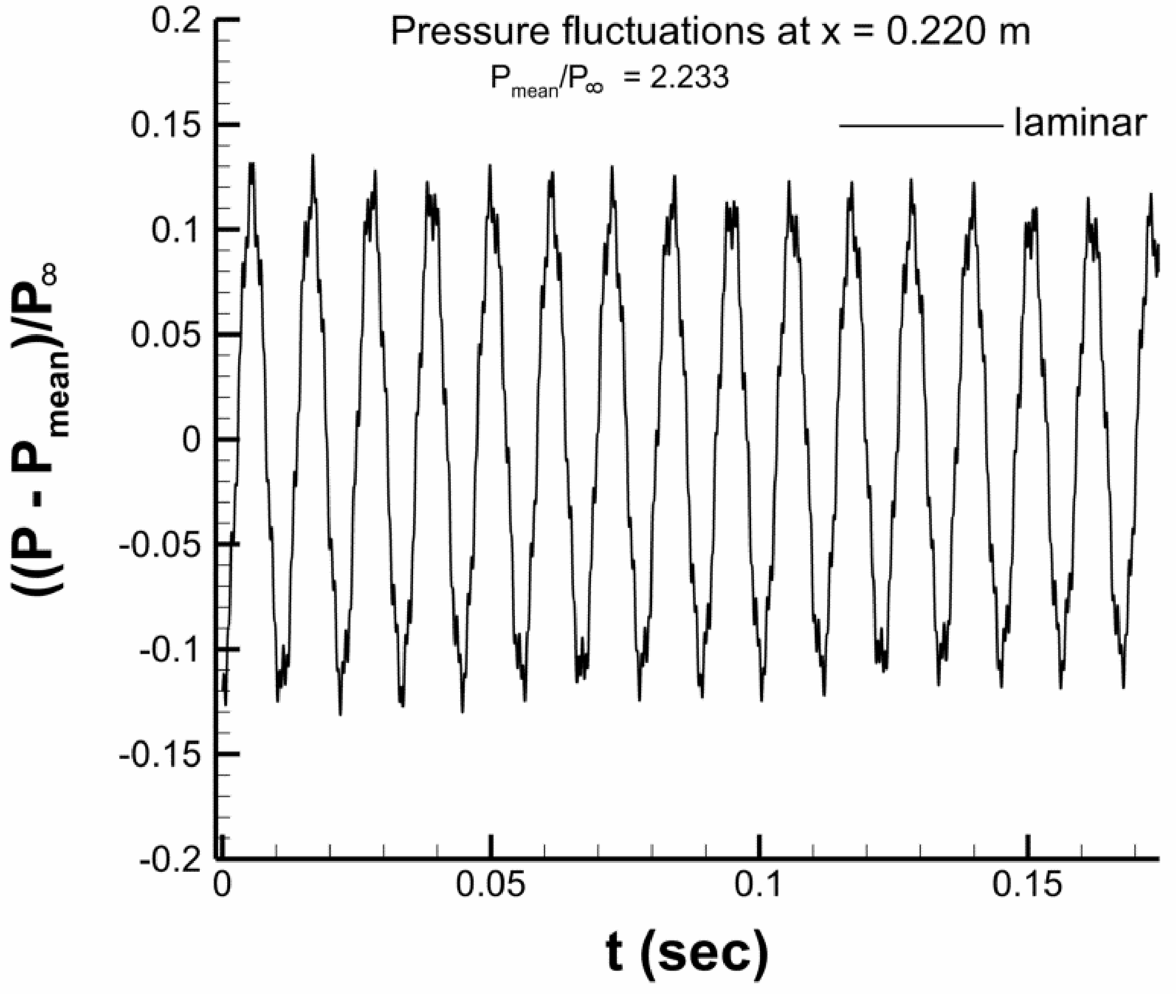


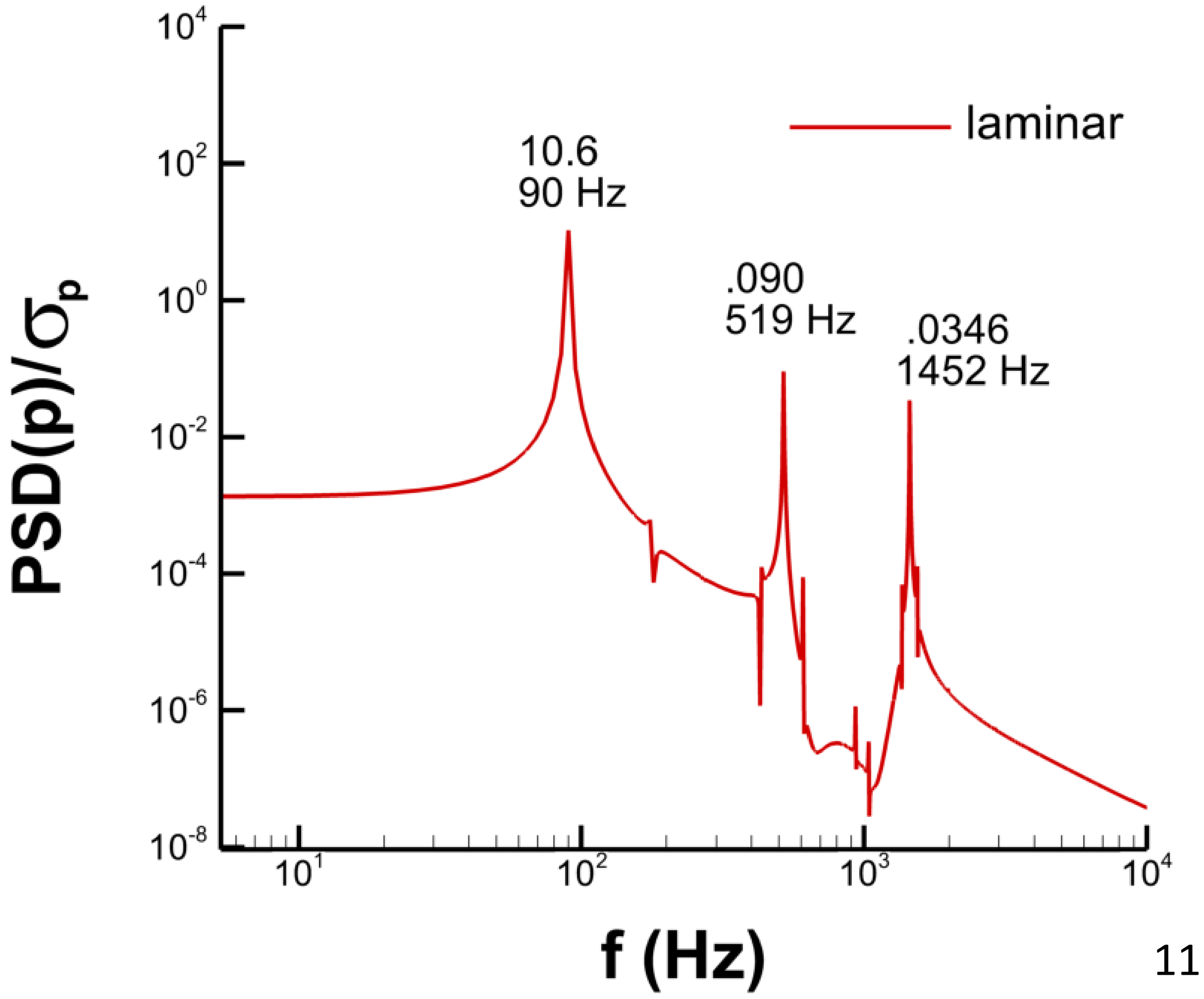
LaRC HyMAX Computational Aeroelastic Computations

- Looking at the experimental data set given in December 2022:
  - This is apparently not the data set we will be comparing to. P_∞ here is lower than our P_∞ = 755 Pa.
  - The data fluctuates at the same rate and roughly magnitude as P_∞.
  - There is quite a large fluctuation in P_∞, but perhaps we can account for that in our data reduction.
    - Do we subtract P_∞ or fluctuating part of P_∞ from pressures P1, P2, P3, P4?
    - This question prompts the following approach, as pressures are presented here as $(P-P_{mean})/P_\infty$.



2 degree turning angle, x = 0.22 m





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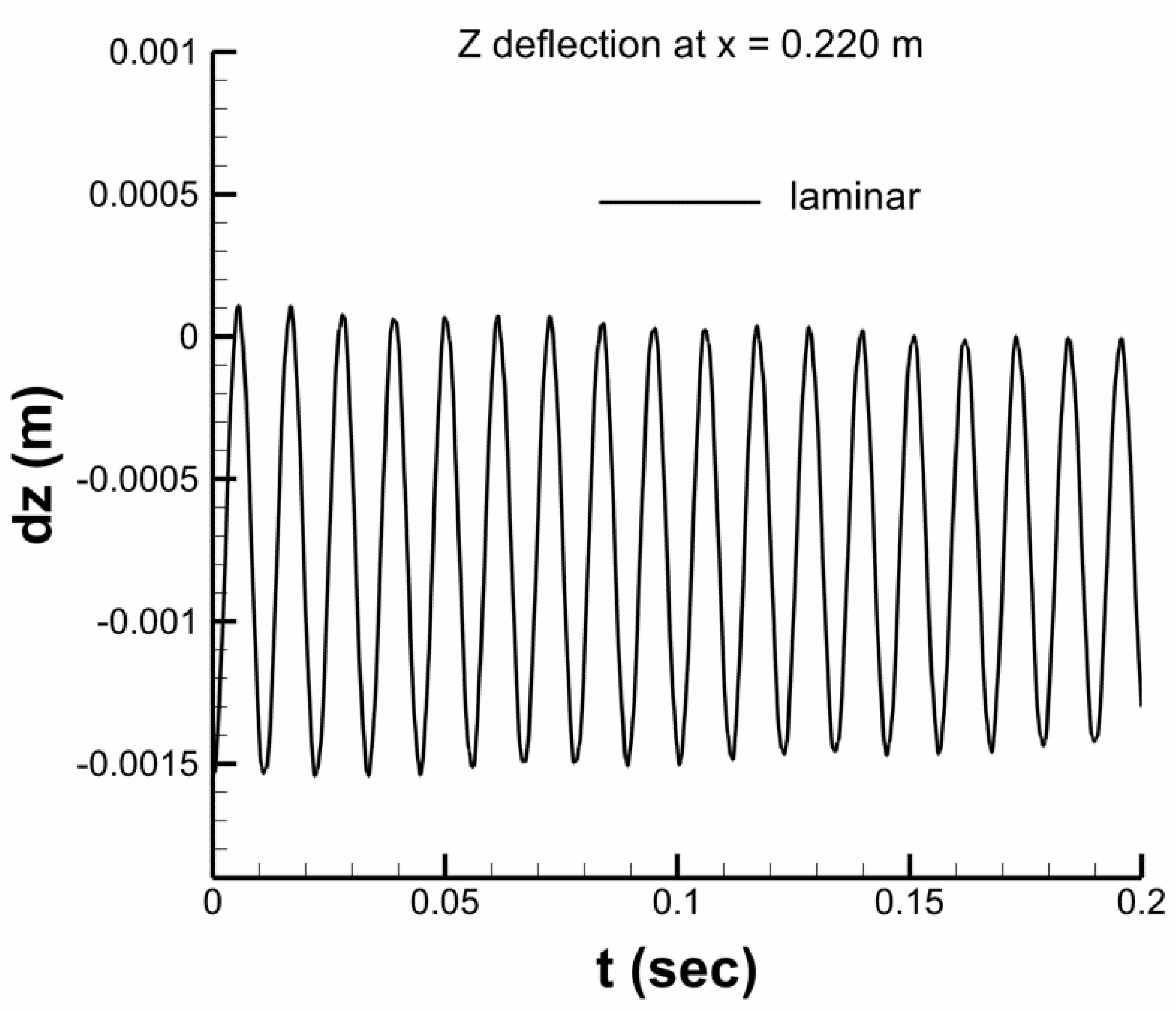
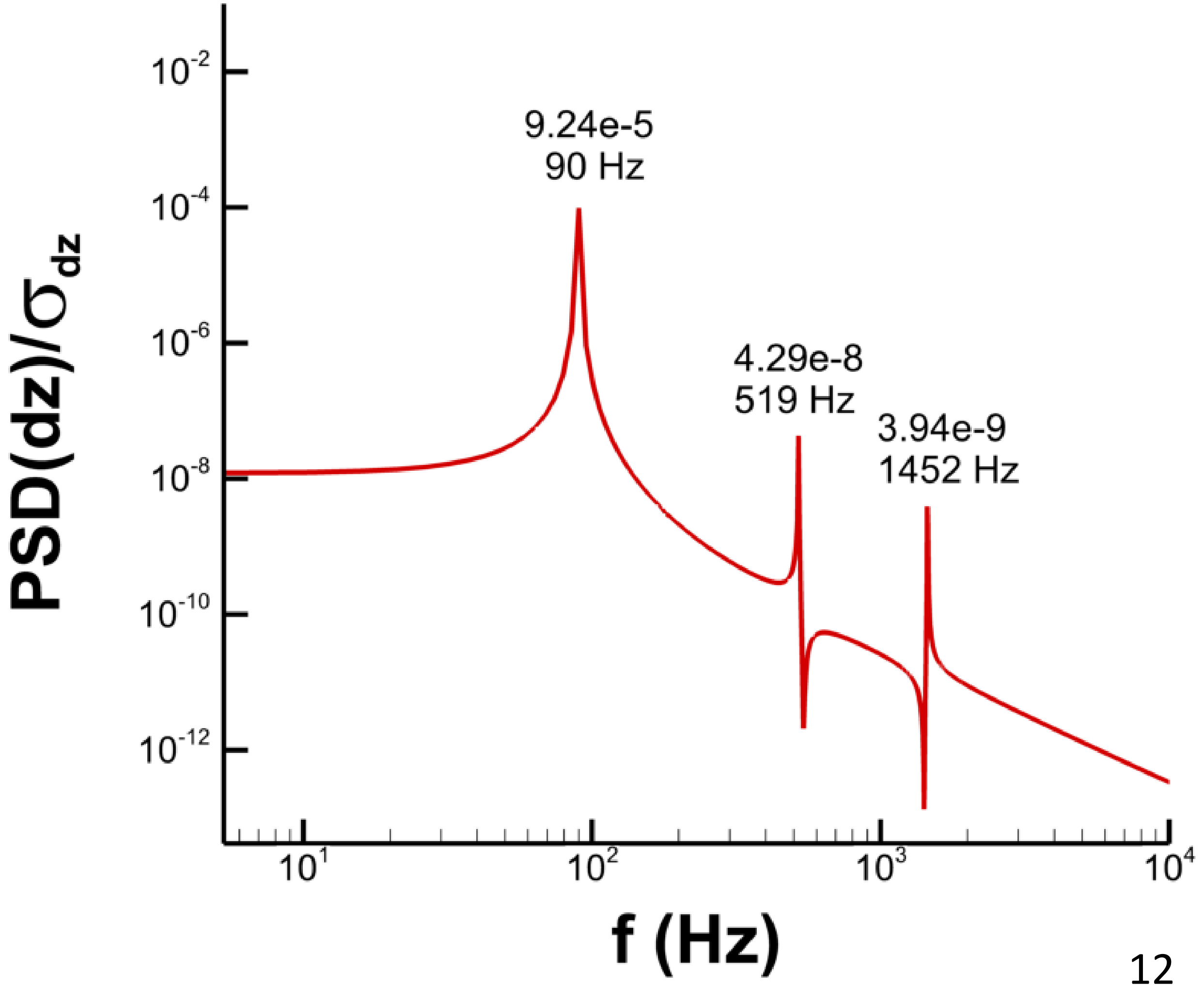
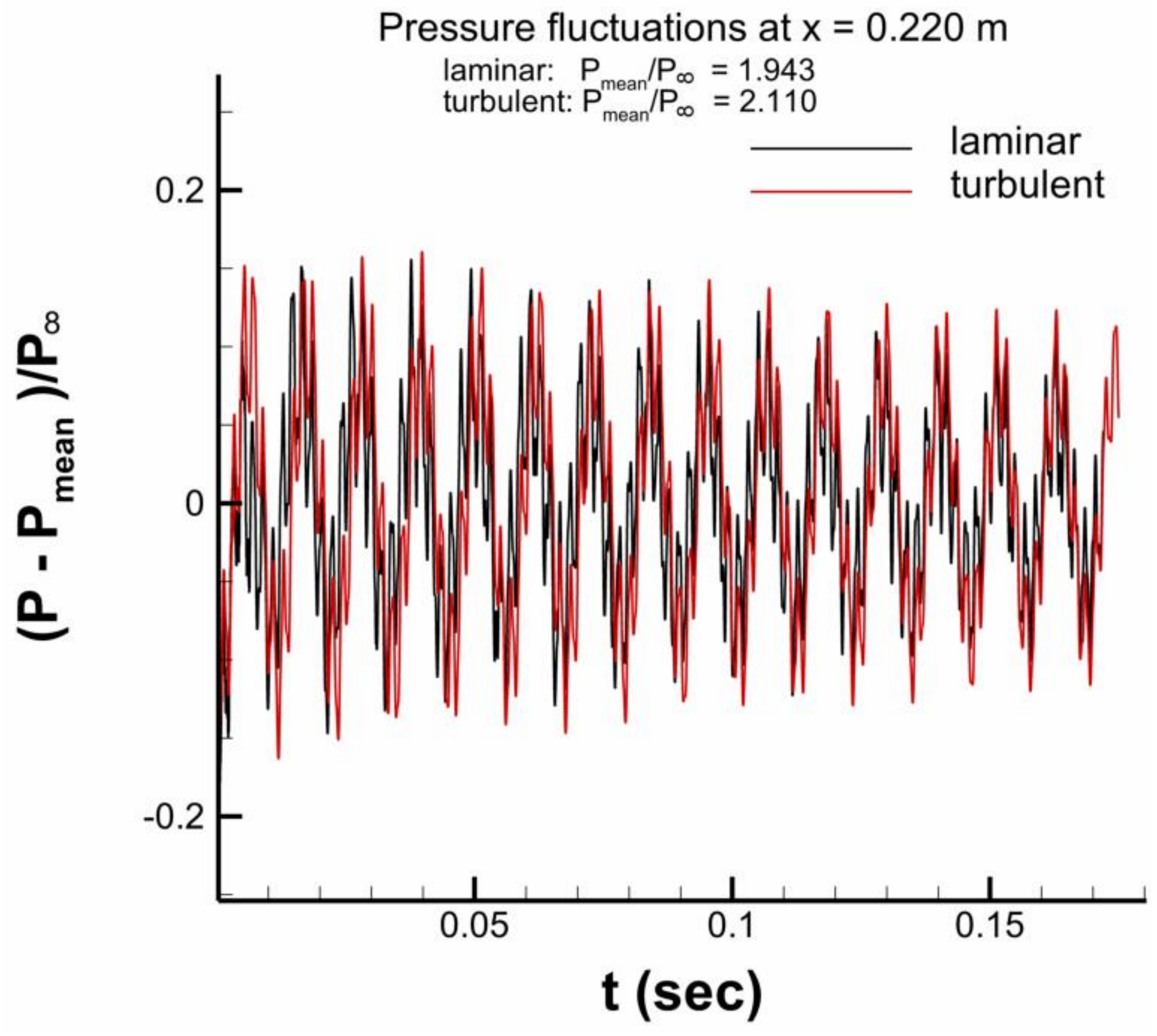
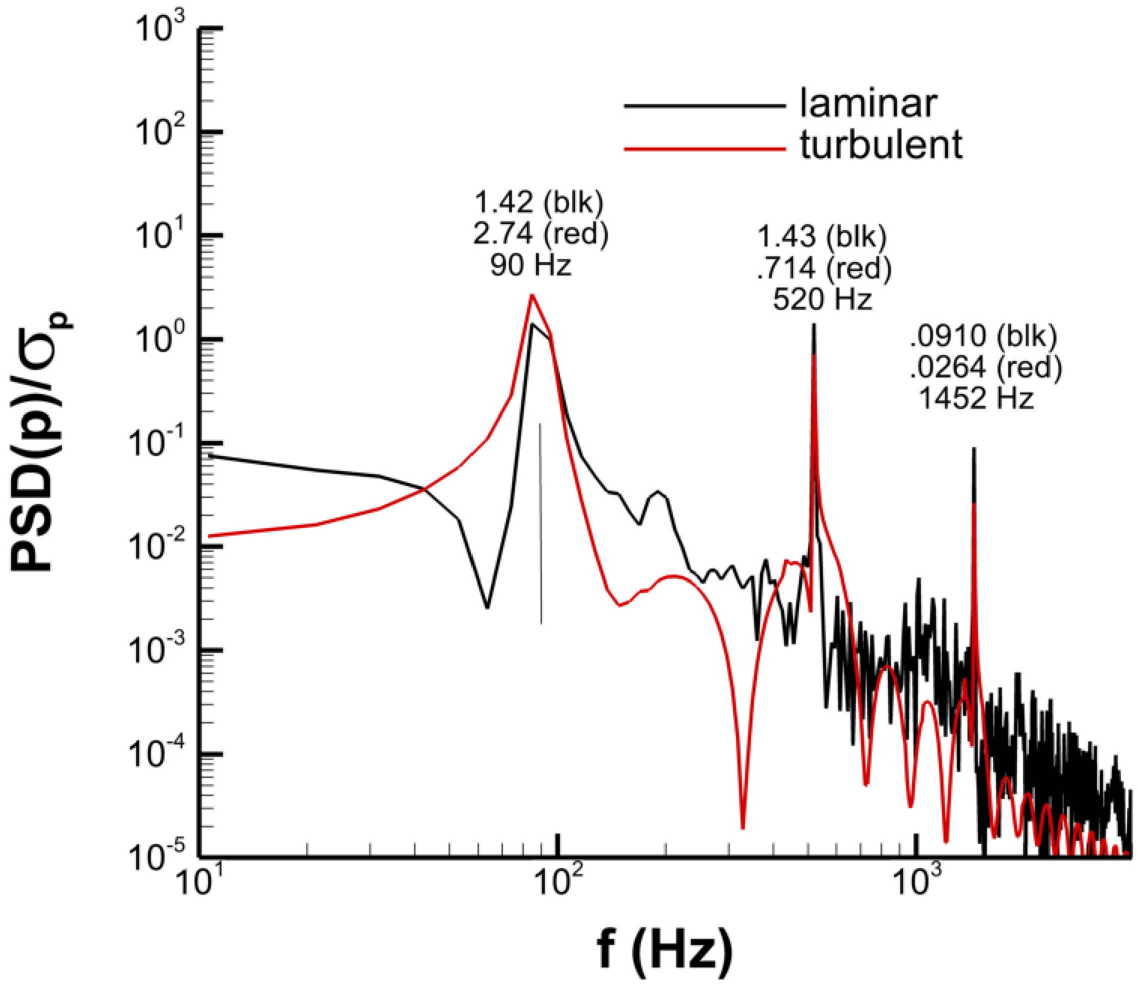




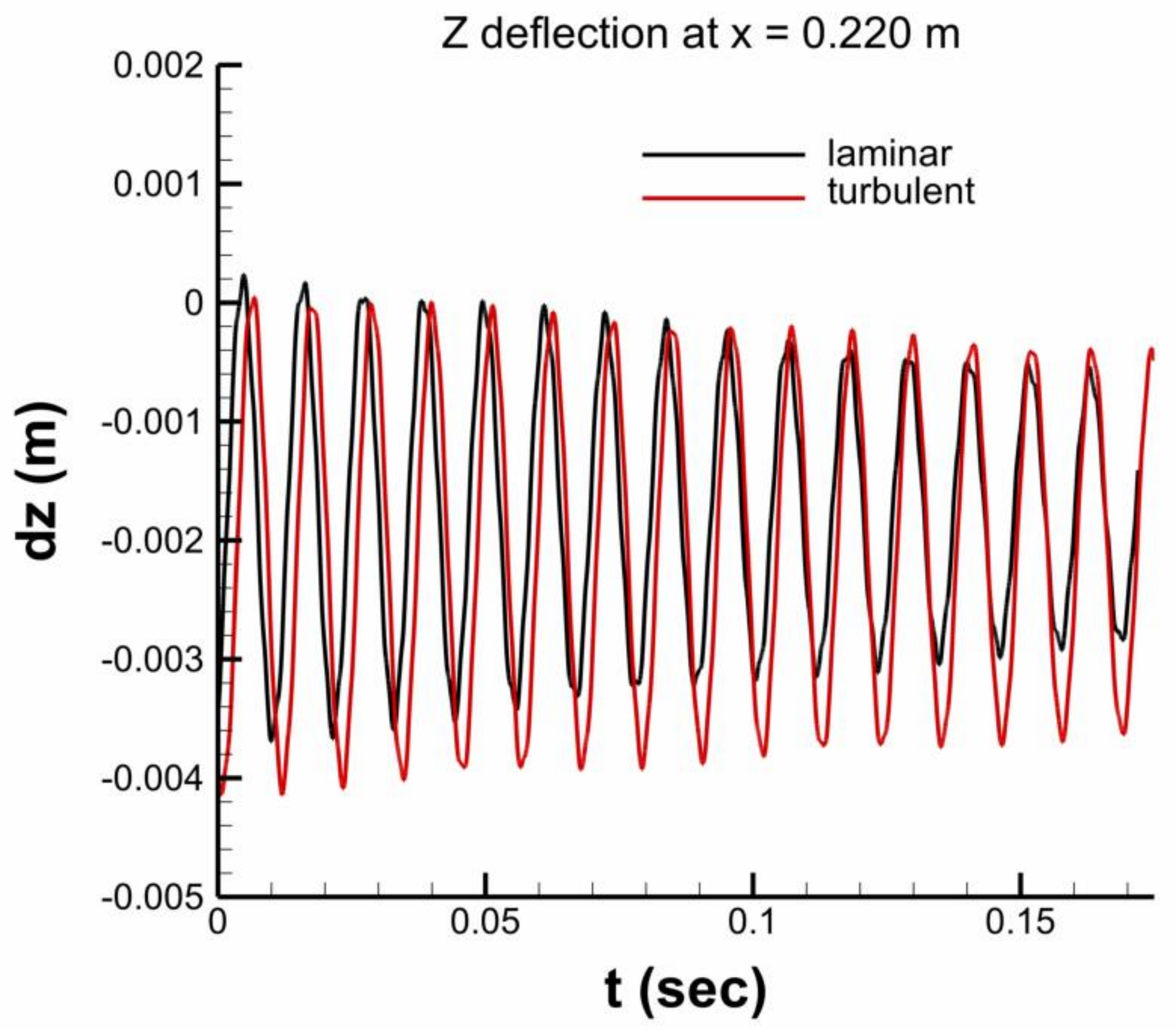
10 degree turning angle, x = 0.22 m

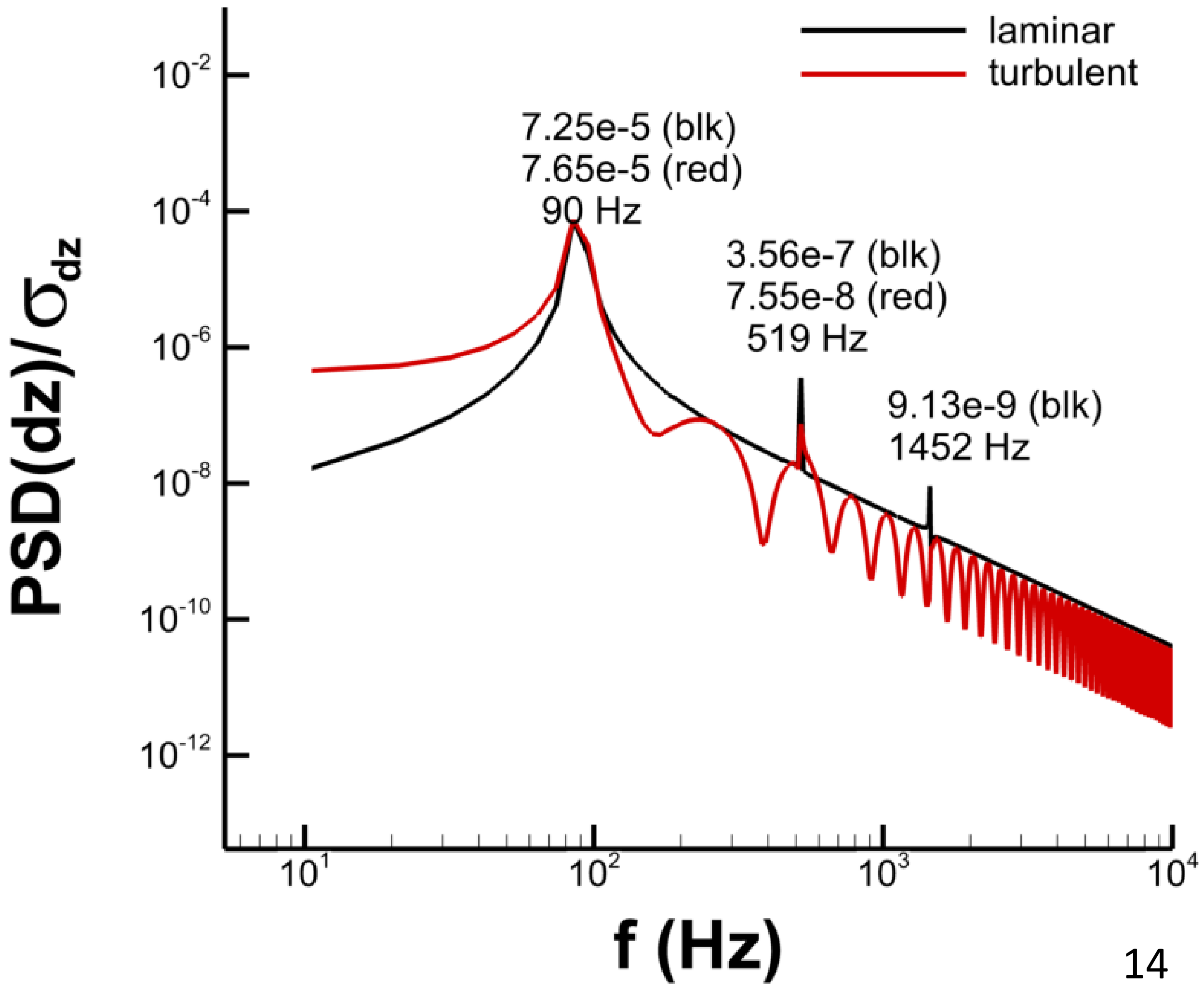




LaRC HyMAX Computational Aeroelastic Computations

10 degree turning angle





Concluding Remarks

- The 2 degree turning angle case:
  - Laminar solution, fluid/structure damping: ζ_s = 0.13-0.18 %.
- The 10 degree turning angle case:
  - Laminar solution , fluid/structure damping : ζ_s = 0.62-0.70 %.
  - Turbulent solution, fluid/structure damping: ζ_s = 0.24-0.30 %.

- There may be additional refinement of the grid, particularly aft of the wedge that may have some impact on the solution.

- Question of how to handle fluctuating P_∞ is a matter for discussion.

- Influence of turbulence model and 3D effects are not addressed in this study.